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ARM Based Design of Density and Viscosity Measuring Instrument for Petroleum

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Abstract*— Real-time viscosity measurement remains a necessity for highly automated industry. The off-line viscosity measuring destroys the real time performance and the precision, and the change of temperature causes a biggish impact to the output. Density is one of the most universal and easily measurable qualitative characteristics of petroleum products. Knowledge of this quantity enables one not only optimize the operation of internal combustion engines but also to grade the petroleum products and take their mass into account. This paper proposed an improved method based on single chip, which realized the on-line signals gathering and the data processing of many kinds of signals, to measure the fluid viscosity. The configuration of the sensor was given, which was designed independently after many times tests and error analysis. The temperature measurement was carried out by temperature sensor and it's signal conditioning circuits.

***Keywords* — Viscosity, Density, Temperature, Viscometer Component, Petroleum, Diesel, Petrol, Kerosene**

I. INTRODUCTION

Density is one of the most prevalent physical properties used to classify and characterize fluids, not only in the environmental, cosmetics, pharmaceuticals, and food and beverage industries, but also in hydrocarbon processing industry (HPI). Petroleum products are everywhere in today's life, and have become almost natural parts of the modern world. Numerous products used on a daily basis are derived from petroleum, such as all kinds of fuels and oils, or the wide range of petrochemicals. The raw material, crude oil, and its refinery products are complex mixtures and usually characterized through their physical properties, including the density value [1]. The different modes of transfer and storage suggest various ways and means of measuring the volumes of fluids under movement. In the process of measurement certain parameters especially Temperature, Densities/ Specific Gravities play such important roles, that tables that are concerned with the effect of temperature on volumes, specific gravities or densities, for example, have been complied jointly by the American Society for Testing Materials (ASTM) and Institute of Petroleum (IP) of United Kingdom [2]. Density is the amount of mass that can be contained in a volume unit. When using internal combustion engines, it is obligatory to determine the density. The standard recommended methods and existing instruments, although they provide the necessary accuracy do not always satisfy practical requirements as regards their construction and conditions of use, since in the majority of the cases they can only be used under stationary laboratory conditions.

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The Viscosity is the thickness of the liquid has an important role in embedded application practice in which the higher is the viscosity the thicker the liquid, the lower the viscosity the thinner the liquid [3]. Often the viscosity of medium of high velocity mixtures must be adjusted at particular temperature. Liquid viscosity is one of the most difficult properties to calculate with accuracy [4]. While the definition also applies to oil, the system used to label the viscosity of passenger car engine oils one of the least understood automotive specifications [3].

According to the Society of Tribologists and Lubrication Engineers (STLE), viscosity is one of oil's most important physical properties. It is often one of the first parameters measured by most oil analysis labs because of its importance to oil condition and lubrication [8].

From the early efflux cups (Shell, Ford, and Zahn cups) to precision gear metered capillary viscometers, the driving force in viscosity measurement technology has been and continues to be petroleum, specifically, oil condition based monitoring for embedded applications [5].

A significant factor in this new technology is that the viscoelastic properties of the liquids being measured have strong dependences on the operating and measurement conditions and the use of a single number to characterize the liquid is a study in futility [5].

Previous attempts in the automotive field were based on measuring the permittivity or conductivity of the oil [9–11]. Although measured directly in the oil, these parameters are of limited use as they are influenced by many different oil wear mechanisms, thus providing a poorly analyzable signal only. There were also attempts to sense a representative chemical parameter (see, e.g., [12]) directly, but chemical sensors commonly exhibit a limited life time only and show adverse properties with respect to aging and drift [6].

The viscosity is considered as one of the most important parameters for the oil's lubrication properties and its inclusion into on-line monitoring systems has been suggested earlier [13]. In laboratory analysis, the measurement of the viscosity is well-established; however, the used viscometers are barely suitable for reliable and cost-effective integration in an on-line monitoring system. In contrast, due to their small size and the absence of macroscopically moving parts, microacoustic sensors appear ideal for this purpose [14].

Every viscosity measurement method tends to probe different rheological aspects of the liquid under investigation, we investigated the rheological aspects associated with the application of microacoustic viscosity sensors for the monitoring of deteriorated engine oils and compared their applicability to conventional viscometers [6].

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This paper is intended to demonstrate that intelligent sensor methods, coupled with ARM processor, provide the technical means to enable affordable embedded monitoring of fuels, and other fluids of critical significance to the military, commercial, and consumer transportation industries as well as to the broader field of industrial process control. Existing technologies are discussed and near-term future developments are outlined [5].

II. BASIC CONCEPTS

A. Density

Liquid density is an important characteristic used to provide information concerning composition, concentration, mass flow in fuels, and caloric content. Density is expressed as mass per unit volume but is often expressed in terms of specific gravity (SGliq), which is the ratio of the liquid density to the density of water both taken at the same temperature and pressure.

Mass (m) is a fundamental measure of the amount of matter. Weight (w) is a measure of the force exerted by a mass and this force is produced by the acceleration of gravity. Therefore, on the surface of the earth, the mass of an object is determined by dividing the weight of an object by 9.8 m/s^2 (the acceleration of gravity on the surface of the earth). Since we are typically comparing things on the surface of the earth, the weight of an object is commonly used rather than calculating its mass.

The density (r) of a material depends on the phase it is in and the temperature. (The density of liquids and gases is very temperature dependent.) Water in the liquid state has a density of 1 g/cm^3 = 1000kg/m^3 at 4° C.

The density of the liquid is mathematically expressed as

$$d = \frac{(W2 - W1)}{V} in(gm/ml) \qquad (1)$$

where,

W1 = weight of the empty specific gravity bottle. (in gm)

W2 = weight of the specific gravity bottle with liquid. (in gm)

V = Volume of the specific gravity bottle. (in ml)

B. Viscosity

Viscosity is a principal parameter when any flow measurements of fluids, such as Liquids, semi-solids, gases and even solids are made.

Viscosity is the measure of the internal friction of a fluid. This friction becomes apparent when a layer of fluid is made to move in relation to another layer. The greater the friction, the greater the amount of force required to cause this movement, which is called *shear*. Shearing occurs whenever the fluid is physically moved or distributed, as in pouring, spreading, spraying, mixing, etc. Highly viscous fluids, therefore, require more force to move than less viscous materials.

Viscosity is defined mathematically by this formula:

$$\eta = \frac{S}{F} \qquad (2)$$

Where,

F′ = shear stress unit of measurement is dynes per square centimeter (dynes/cm^2).

S = shear rate unit of measure is reciprocal second (sec^{-1}).

The fundamental unit of viscosity measurement is the poise. A material requiring a shear stress of one dyne per square centimeter to produce a shear rate of one reciprocal second has a viscosity of one poise, or 100 centipoise. You will encounter viscosity measurements expressed in *Pascal-seconds* (Pa·s) or *milli-Pascal-seconds* (mPa·s); these are units of the International System and are sometimes used in preference to the Metric designations. One Pascal-second is equal to ten poise; one milli-Pascal-second is equal to one centipoise.

Lubricating oil's viscosity is typically measured and defined in two ways, either based on its kinematic viscosity or its absolute (dynamic) viscosity [3].

- Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. It is frequently measured using a device called a capillary viscometer. It is basically a graduated can with a narrow tube at the bottom. When two fluids of equal volume are placed in identical capillary viscometers and allowed to flow under the influence of gravity, a viscous fluid takes longer than a less viscous fluid to flow through the tube.

The kinematic viscosity (represented by the symbol ν "nu") is the ratio of the viscosity of a fluid to its density.

$$\nu = \frac{\eta}{\rho} \qquad (3)$$

- The dynamic viscosity of a fluid is defined as the shear stress applied divided by the velocity gradient achieved when a shear force is applied to a fluid. Viscosity varies greatly among fluids. It is important in the flow behavior of liquids.

The kinematic viscosity of the liquid which is calculated using density is mathematically expressed as

$$\eta = \frac{d2}{d1} * \frac{Tm2}{Tm1} * \eta dw \quad (\text{inpoise}) \qquad (4)$$

where,

d1 = density of the liquid to be measured. (in gm/ml)

d2 = density of the distilled water as a reference. (in gm/ml)

tm1 = mean time to flow the liquid in capillary tube between two reference points. (in sec)

tm2 = mean time to flow the distilled water in capillary tube between two reference points. (in sec)

η_{dw} = viscosity of the distilled water = 1 poise (standard).

C. Density Sensors

Ultrasonic Liquid Density meter has the center frequency of the ultrasonic transducer is 1MHz. For a particular liquid, coefficient of volume compressibility K is a constant. If we have the ultrasonic propagation velocity in the liquid, we can calculate the density of liquid. [17].

Magnetostriction Sensor The effect of density change on liquid level was investigated by considering of five liquids which density varies from 0.69 to 0.89 g/cm3. Measurement of density for oil in big tank is also an intractable problem for gauging people since media's density varies at different height. The change of media density has some effect on measuring precision, and sometimes error will be great [18].

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Novel Sensor In recent practical industry producing fields, the density measuring are usually used differential pressure densimeter or bobber densimeter with the accuracy about 1-5 percent. To the higher-accuracy requirements of fluid density measuring and analysis, it is apparent that they are hardly satisfied. the measuring accuracy of this novel densimeter had a higher accuracy than the traditional measuring devices and systems as the differential pressure densimeter and the bobber densimeter; meanwhile, although its measuring accuracy lower than the capacitance-type densimeter but its performance of antibad- environment is excellent than the capacitance-type densimeter [19].

OPW Magnetostrictive Sensor for the Density Measurement is easily install on Probe. The SiteSentinel® family Density Measurement Sensor uses a single magnetostrictive in-tank probe assembly. The sensor continuously measures the density of the fuel in the tank, but not provide the smallest changes in the product [18].

D. Viscosity Sensor

There is a continuous demand for real time monitoring of petroleum. The various sensor principles are available for the viscosity measurement as SHAPM (Shear Horizontal Acoustic Plate Mode) sensor, TSM-MPS (Thickness Shear Mode – Monolithic Piezoelectric Sensor) sensor, Micro-acoustic sensors, piezoelectric BAW sensors, BICONVEX Quartz Crystal, Solid State Sensors, Optical sensors etc.

In 2003 there was introduction of an analog viscosity sensor for the viscosity measurement based on SHAPM technology. The SHAPM sensor measures different apparent properties of the liquid than the properties seen by most oil viscosity engineers. These sensors are use to conduct real-time detection of oil viscosity degradation as a function of temperature [5].

The resonant piezoelectric BAW sensors has output measurement quantity as frequency. Frequency output allows conversion from analog to digital values by use of a counter with virtually no limitation of the dynamic range by the measurement principle itself [15]. The presence of piezoelectric BAW sensors in industry is not very widespread, mainly due to higher costs of complete measuring systems. Such a system comprises resonator, sensor head and sophisticated supporting electronics [7].

Sensing of viscosity is useful only if the actual temperature of the liquid is known. To get correct results, it is advantageous to measure temperature as near as possible to the position where viscosity is measured. The sensor according to fulfills this requirement. This system based on the Optical sensor combined with the ARM processor.

E. Background

The load cell sensor with it's amplifier or digitizer board is used. A load cell is a transducer that is used to convert a force into electrical signal. The most common use of this sensor is in weighing machine. Every weighing machine which shows weight has a load cell as sensing element. The amplifier or digitizer board is total solution for analog front end for Load Cell applications. This signal is then fed to the ARM processor for further calibration.

Attempts to employ miniature versions of mechanical viscometers have been largely unsuccessful due to issues with clogging, fouling, and vibration. Virtually all sensor development efforts for this viscosity measurement application employ optical sensor with ARM processor as hybrid systems.

Since the sensors are intended for in situ, embedded, point-of use measurements, recalibration per se is not usually an option. Instead, an adaptability mechanism is introduced. Upon changing the target fluid, the system signals to the sensor that fresh lubricant has been introduced. The sensor monitors the viscosity versus temperature of the fresh fluid, ensuring that its properties are within the serviceability specifications of the equipment while also establishing a baseline against which deterioration may be evaluated.

F. Contribution Of The Paper

A particular challenge of the sensor is to embed all of the calibration data, adaptive baseline data, and instrumentation and processing power into a suitably small device while still allowing the sensor to operate reliably over the entire automotive temperature range.

III. BLOCKWISE SYSTEM REPRESENTATION

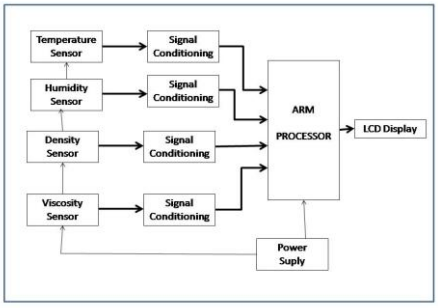

Fig. 8: Block Diagram of Measurement System

- Temperature Sensor with Signal Conditioning

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The practical full temperature range is from −55° to +150°C. It operates from 4 to 30 volts.

- Humidity Sensor with Signal Conditioning

It converts relative humidity to equivalent output voltage. The temperature range is from 0° C to +60°C. It's operative humidity is 30 – 90% RH.

- Density Sensor with Signal Conditioning

A load cell is a transducer that is used to convert a force into electrical signal. This conversion is done in two stages. Through a mechanical arrangement, the force being sensed deforms a strain gauge. as an electrical signal, because the strain changes the effective electrical resistance of the wire. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration.

The electrical signal output requires amplification by an instrumentation amplifier before it can be used. The output of the transducer is plugged into an algorithm to calculate the force applied to the transducer.

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This board is highly integrated in the sense and it contains Instrumentation Amplifier, Analog to Digital Convertor and Digitizer which outputs serial data of 9600 baud rate for direct reading in kilograms. The output can be used to connect to microcontroller for further display and processing.

The empty gravity bottle is placed on the Load cell assembly for measuring the weight (W1). The same bottle is filled with the liquid and measure the weight (W2). In this way density is calculate by the processor

- Viscosity Sensor with Signal Conditioning

Capillary U tube viscometer is used along with optical sensor. Two sets of optical sensors are set at two different positions. Position A which is available at the top of the orifice and position B is available at the bottom of the same orifice. The liquid is to be tested is inserted in the tube from first openings and suck through the blower up to another end. The liquid level is adjusted at position A and the timer starts counting. As the liquid level crosses position B the timer stops. In this way the mean time and viscosity is calculated by the processor.

- ARM Processor

ARM processor has the benefits over the simple micro controller. The benefits are listed below

✓ARM executes almost all the instruction in only one cycle where as 8051 micro controller takes more than one cycles in almost all the instruction except register transfer.

✓ARM is a RISC based architecture. 8051 is a CISC.

✓ARM is based on load store architecture.

✓ARM have conditional data processing instruction where as 8051doesnot.

The sensor signals should provide information about the actual physical/ chemical oil quality in order to complete the information needed by the prediction algorithms, as shown

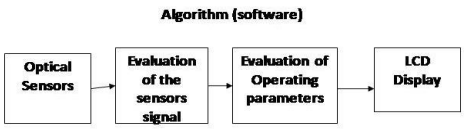

Fig. 13: Prediction Algorithm [6]

IV. RESULTS

I. Density by standard and by setup.

Liquid	W1 in gm	W2 in gm	(W1-W2)/V in gm/ml	Observed in gm/ml
Distilled Water				
Diesel by 25 ml bottle	29.58	50.56	0.83	0.86
Diesel by 50 ml bottle	16.59	60.24	0.87	0.87
Diesel by 350 ml bottle	217.69	526	0.88	0.87
Kerosene by 25 ml bottle	29.58	49.90	0.81	0.82
Kerosene by 50 ml bottle	16.59	58.92	0.84	0.83
Kerosene by 350 ml bottle	217.69	516	0.85	0.84
Petrol by 25 ml bottle	29.58	48.16	0.74	0.75
Petrol by 50 ml bottle	16.59	55.42	0.76	0.76
Petrol by 350 ml bottle	217.69	488	0.77	0.76

- This will reflect that the density error between setup and standard method is by 0.01-0.03 gm/ml.

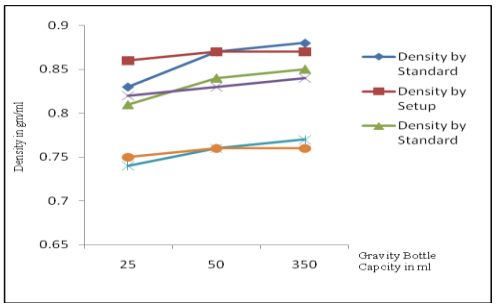

Fig. 14 : Comparative Graphical representation of Density Results from Standard and Setup Methods for Diesel, Kerosene and Petrol.

II. Viscosity dependency on temperature by manual and by setup.

Tempe rapture	Humi dity	Viscosity of Diesel in poise		Viscosity of Kerosene in poise		Viscosity of Petrol in poise	
In ^{0}C	In %RH	Manua l	Setup	Manua l	Setup	Manua l	Setup
28	20	2.29	2.42	1.26	1.27	0.70	0.70
30	37	2.28	2.35	1.24	1.25	0.70	0.69
32	40	2.28	2.34	1.23	1.24	0.69	0.67
34	45	2.27	2.30	1.22	1.23	0.68	0.64
36	49	2.26	2.27	1.21	1.22	0.67	0.64
38	53	2.25	2.26	1.20	1.21	0.67	0.63
40	60	2.24	2.25	1.20	1.21	0.66	0.63

- As the temperature increases the viscosity starts decreasing, hence viscosity is inversely proportional to the temperature.

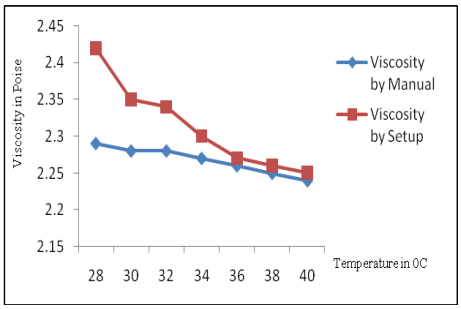

Fig. 15 : Comparative Graphical representation for variation of Viscosity with respect to Temperature by Mannual and Setup Methods for Diesel.

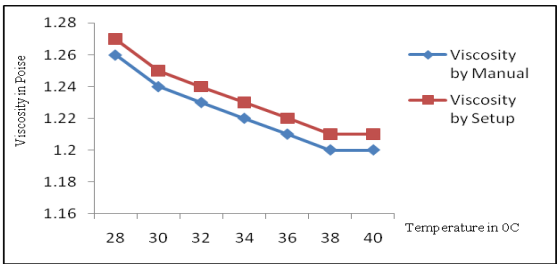

Fig. 16 : Comparative Graphical representation for variation of Viscosity with respect to Temperature by Mannual and Setup Methods for Kerosene.

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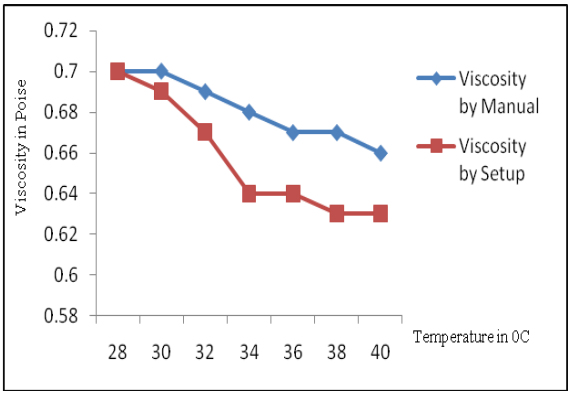

Fig. 17 : Comparative Graphical representation for variation of Viscosity with respect to Temperature by Mannual and Setup Methods for Petrol.

III. Viscosity dependency on Density by manual and by setup for Diesel.

Manual		Setup	
Density in gm/ml	Viscosity in poise	Density in gm/ml	Viscosity in poise
0.88	2.29	0.88	2.42
0.87	2.28	0.86	2.35
0.86	2.28	0.86	2.34
0.85	2.27	0.85	2.30
0.84	2.26	0.84	2.27
0.83	2.25	0.83	2.26
0.82	2.24	0.83	2.25

- This indicates that the relation between the Density and Viscosity. As the Density decreases the viscosity starts decreasing, hence viscosity is directly proportional to the temperature.

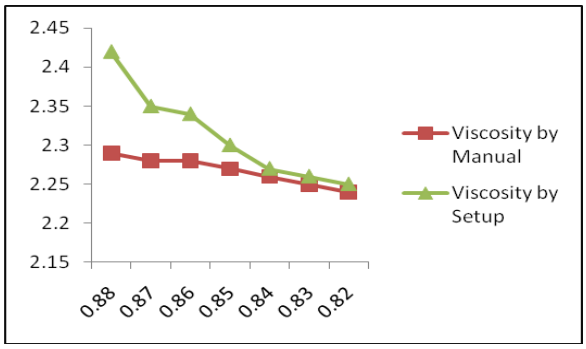

Fig. 18 : Comparative Graphical representation for variation of Viscosity with respect to Density by Mannual and Setup Methods for Diesel.

IV. Viscosity dependency on Density by manual and by setup for Kerosene.

Manual		Setup	
Density in gm/ml	Viscosity in poise	Density in gm/ml	Viscosity in poise
0.86	1.26	0.85	1.27
0.85	1.24	0.84	1.25
0.84	1.23	0.84	1.24
0.83	1.22	0.83	1.23
0.82	1.21	0.83	1.22
0.81	1.20	0.82	1.21
0.80	1.20	0.82	1.21

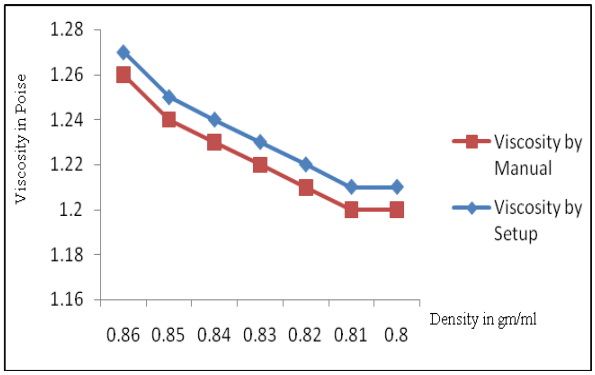

Fig. 19 : Comparative Graphical representation for variation of Viscosity with respect to Density by Mannual and Setup Methods for Kerosene.

V. Viscosity dependency on Density by manual and by setup for Petrol.

Manual		Setup	
Density in gm/ml	**Viscosity in poise**	**Density in gm/ml**	**Viscosity in poise**
0.76	**0.70**	**0.77**	**0.70**
0.75	**0.70**	**0.77**	**0.69**
0.74	**0.69**	**0.76**	**0.67**
0.73	**0.68**	**0.76**	**0.64**
0.72	**0.67**	**0.75**	**0.64**
0.71	**0.67**	**0.74**	**0.63**
0.70	**0.66**	**0.73**	**0.63**

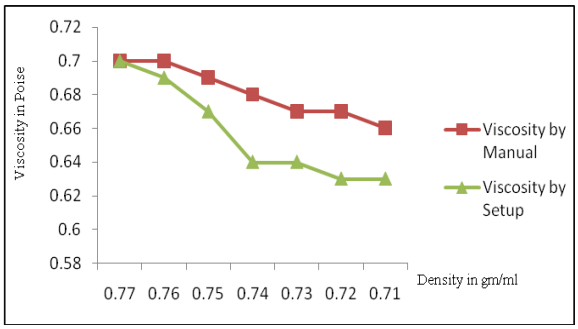

Fig. 20 : Comparative Graphical representation for variation of Viscosity with respect to Density by Mannual and Setup Methods for Petrol.

V. CONCLUSION AND FUTURE WORK

A. Conclusion

This liquid density detection device has the features as follows: the volume is small, the structure is simple and the performance of anti-interference is very strong. It is able to detect the density of liquid. The results show that this density detection device meets the actual needs, and has a high application value.

There is a concerted effort by several automobile manufacturers as well as numerous military and commercial vehicle manufacturers and end-users to develop a reliable, affordable, and meaningful in situ oil condition monitor.

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Such a sensor would require long lifetimes (10 years) without recalibration, would need to measure the oil condition at shear rates relevant to its function, would ideally operate over the entire automotive/ military temperature specification (−55 to +150◦C), and would be insensitive to high vibration, solvent exposure, corrosive chemicals, and abrasive conditions.

To date, the method selected in this paper appears to be favored primarily because it provides good correlation to extremely low shear laboratory data and provides kinematic viscosity. This paper argues that properly implemented system offer better reliability, is more rugged in corrosive and abrasive environments, and measure properties more relevant to the actual conditions of use of the lubricant.

B. Future Work

The temperature sensor, humidity sensor and optical sensor does not inserted directly to the fuels, it results in to short-circuit, corrosion, and gumming. The sensor system will not reliable for direct contacting with the fuels.

So the sensors are chemically passivated and electrically insulated hermetic seal for its electronics. This approach has been found to be necessary in any real measurement environment intended for long-term operation. It also represents best practice for cases in which an explosive hazard could potentially exist, such as extreme fuel dilution.

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